

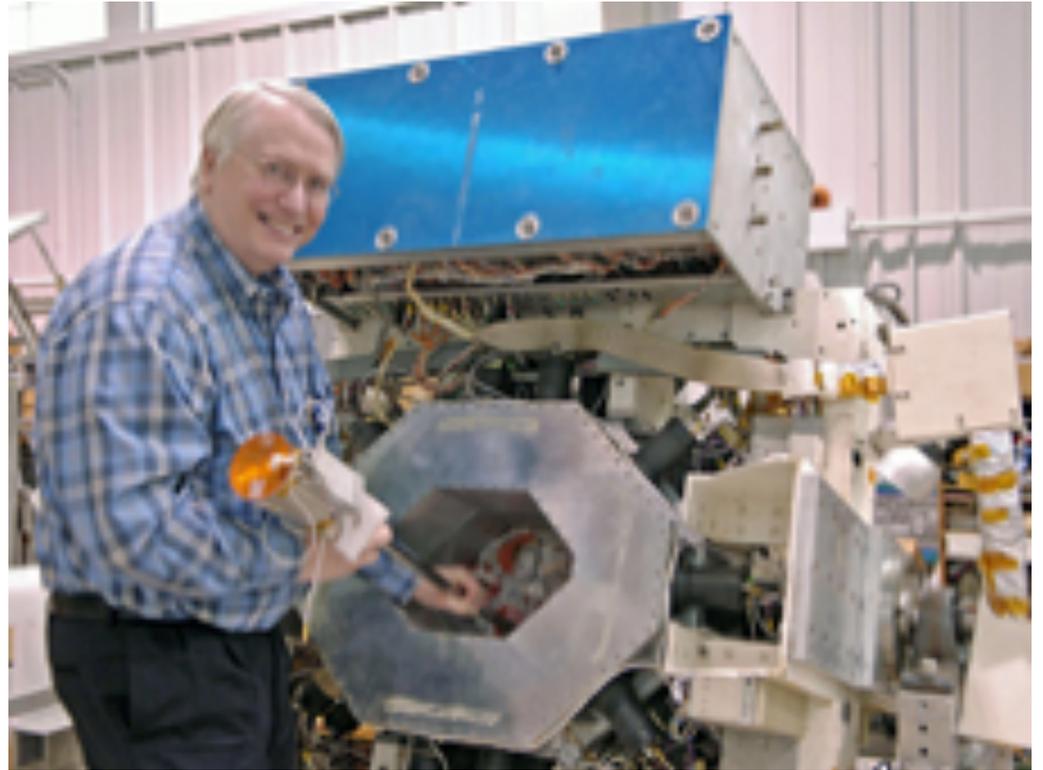
14 Years of the Swift BAT Survey- not just for bursts!

The Survey data allows the study of many types of astrophysical objects in **new** ways producing **unexpected and exciting results – totally unanticipated at launch**

Continuous encouraging support from Neil made this long term project possible.

>110 referred papers with ~2800 citations + 5 PhD Thesis (L. Winter, M. Koss, T. Shimizu, K. Smith (Univ of Md), M. Ajello)

BAT team
Scott Barthelmy, Gerry
Skinner, C. Markwardt,
W. Baumgartner, **Jack
Tueller** (1949-2013)



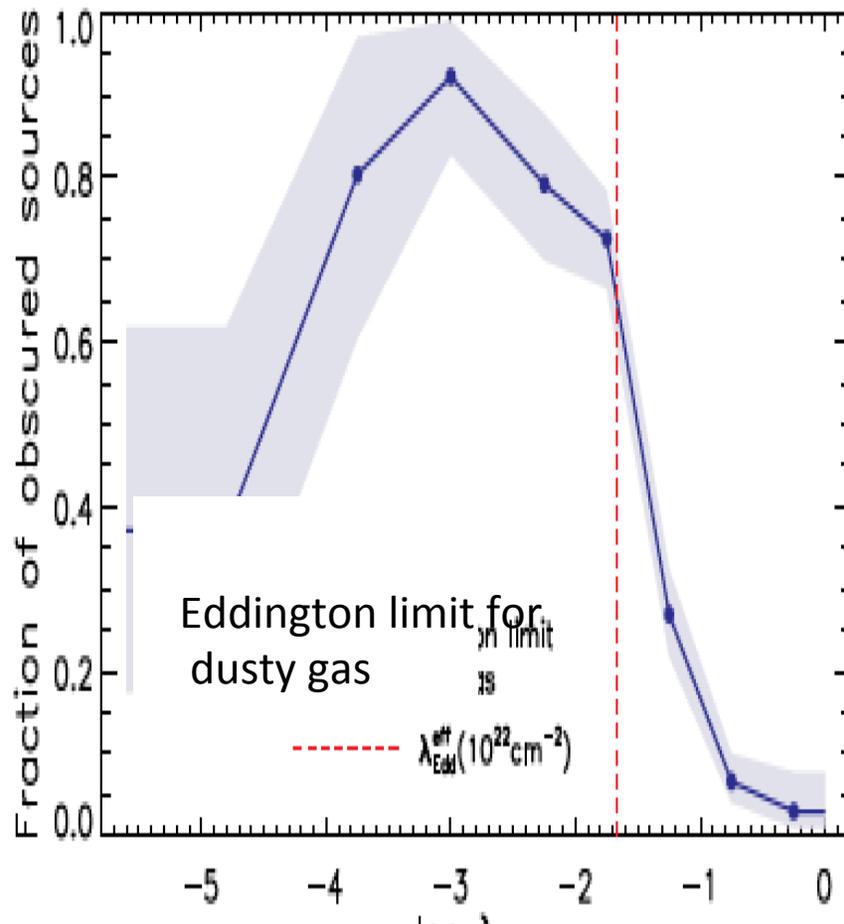
A large group of collaborators (M. Koss (and the BASS team), M. Melendez, T. Shimizu, K. Smith, L. Winter etc)

There also has been a **lot** of work by other teams (e.g. M. Ajello and co-workers, L. Bassani and co-workers, G. Cusumano and the Palermo group, N Masetti and co-workers, G. Tagliaferri and colleagues, Burenin et al)

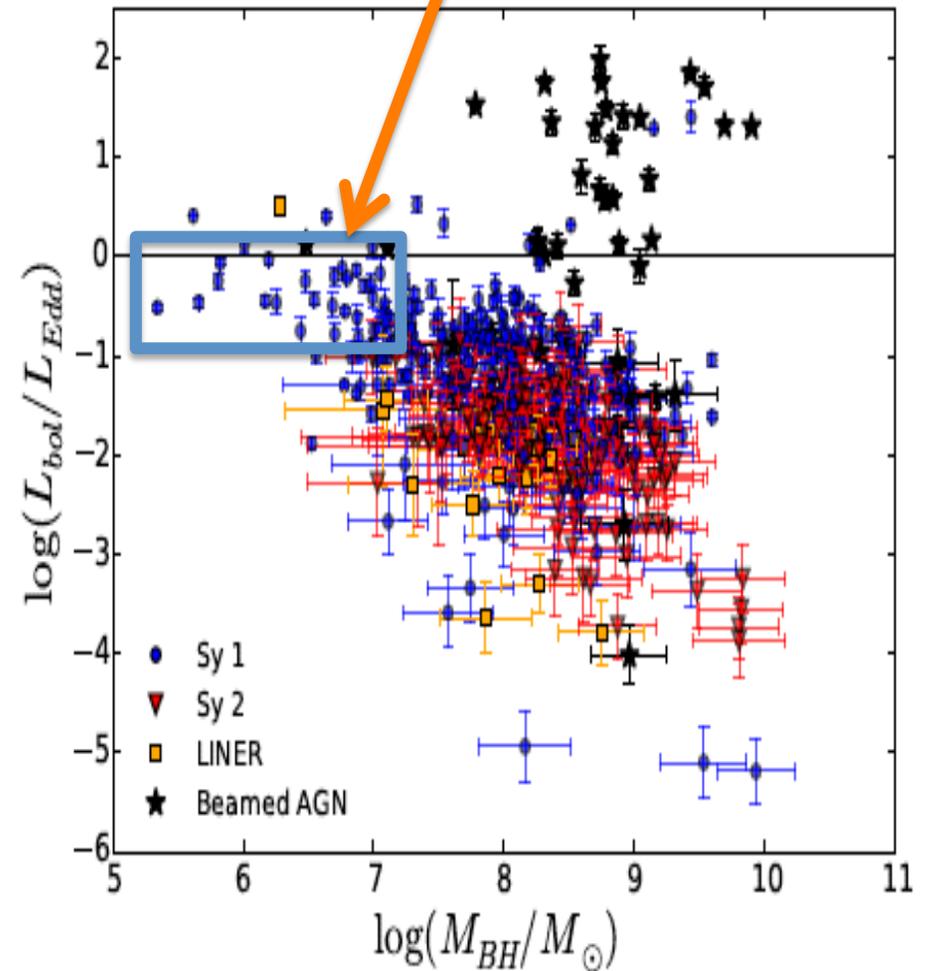
Recent Important AGN Results From the Survey

- Best estimate of number of Compton thick AGN in local universe
- Discovery that the *fundamental difference* between type I and II AGN is their Eddington ratio (a 70 year old problem)
- Confirmation that optical and IR surveys in low Z universe 'miss' a large fraction of AGN
- Direct evidence that presence of an AGN is related to reduction in star formation rate (smoking gun of *feedback?*)- major goal of 2010 Decadal survey

Eddington Ratio and Obscured Sources (Ricci et al 2017, Nature)



Eddington Limited Dwarf AGN



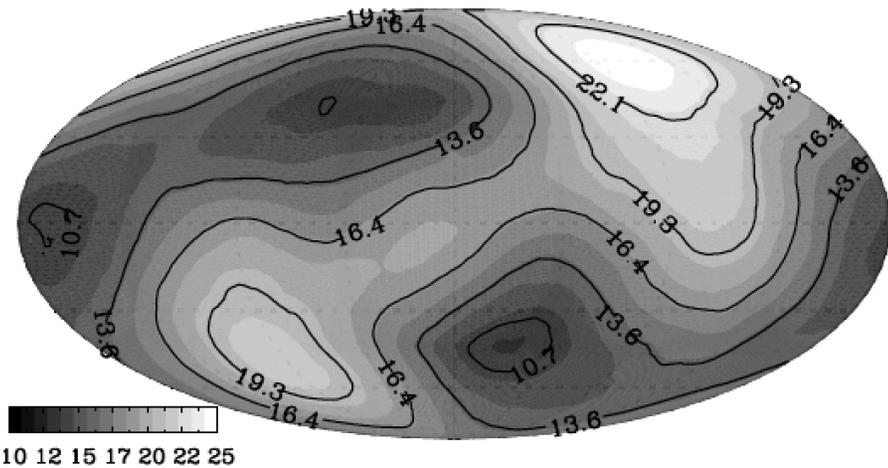
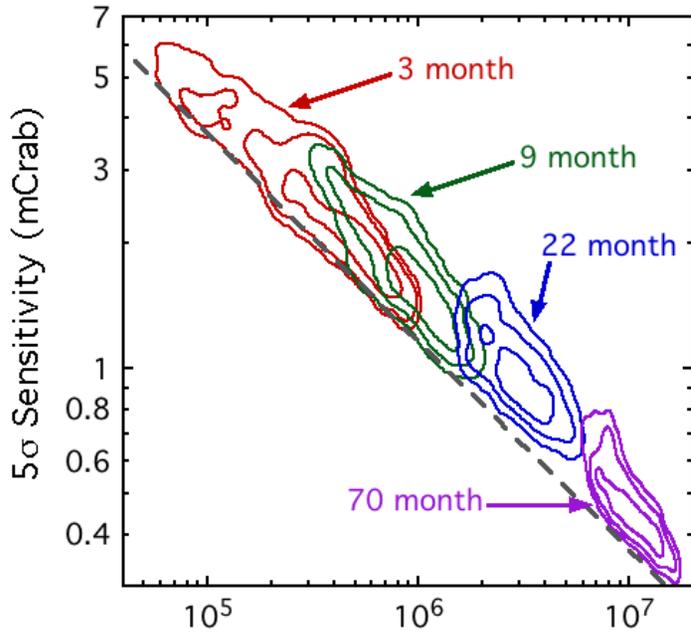
What is in the future

- Timing Analysis
 - The Swift BAT survey : ONLY AGN survey with continuous long term light curves for 100's of AGN and x-ray binaries - barely tapped

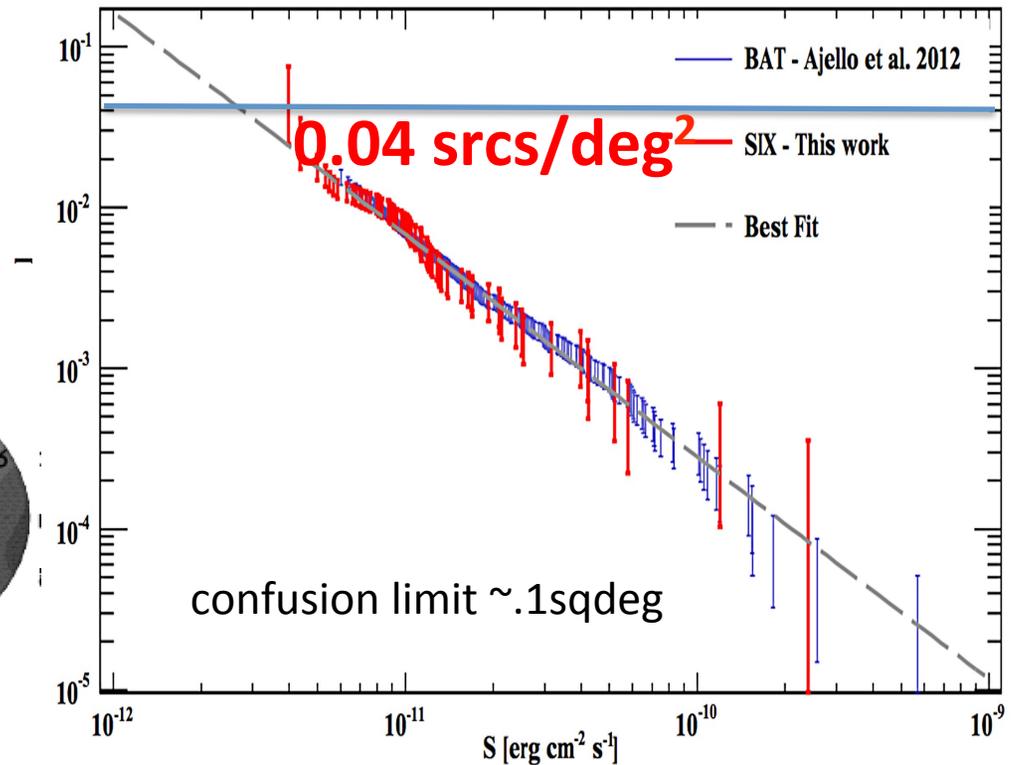


Bat Survey Sensitivity All sky $0.4 \text{ mCrab} = 1 \times 10^{-11} \text{ ergs/sec/cm}^2$

~60x better than best previous all sky survey in the 14-195 keV band



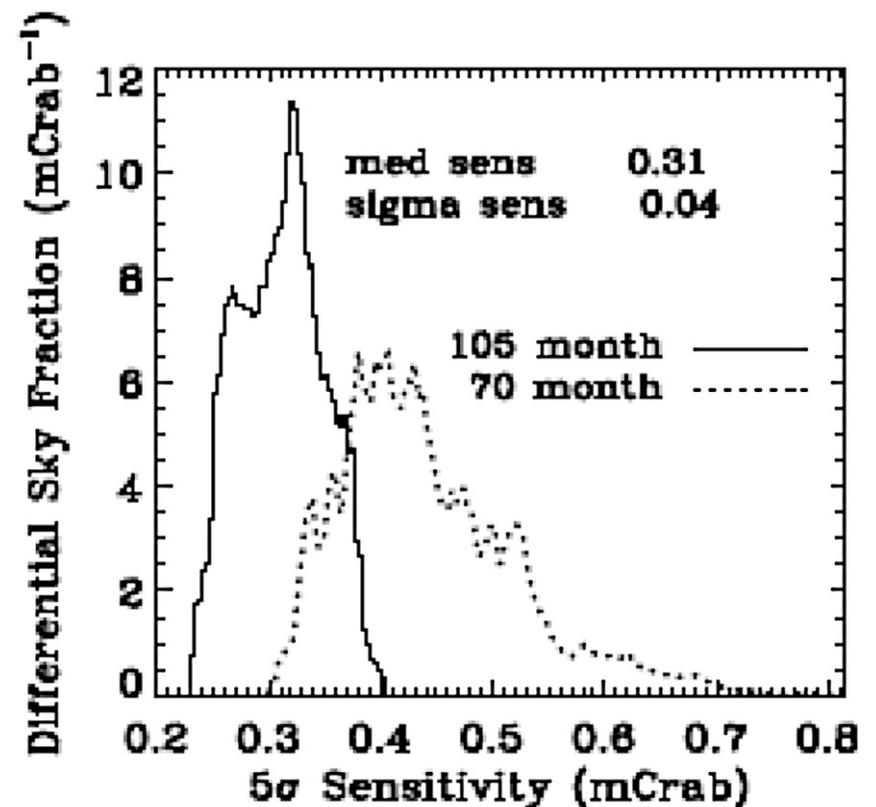
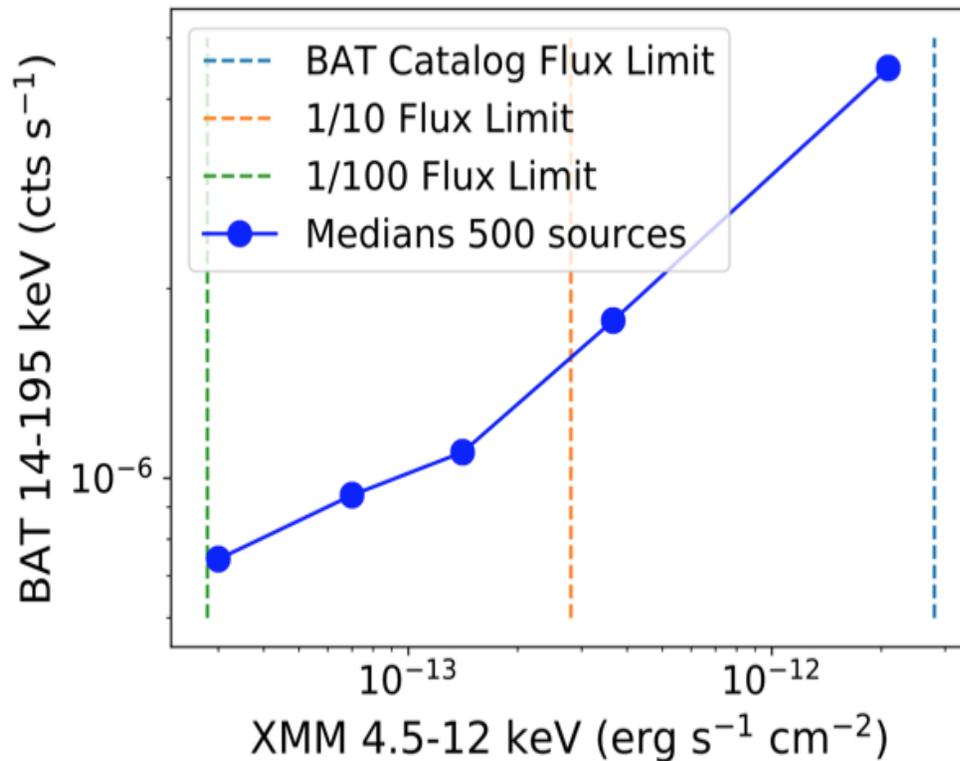
BAT sensitivity



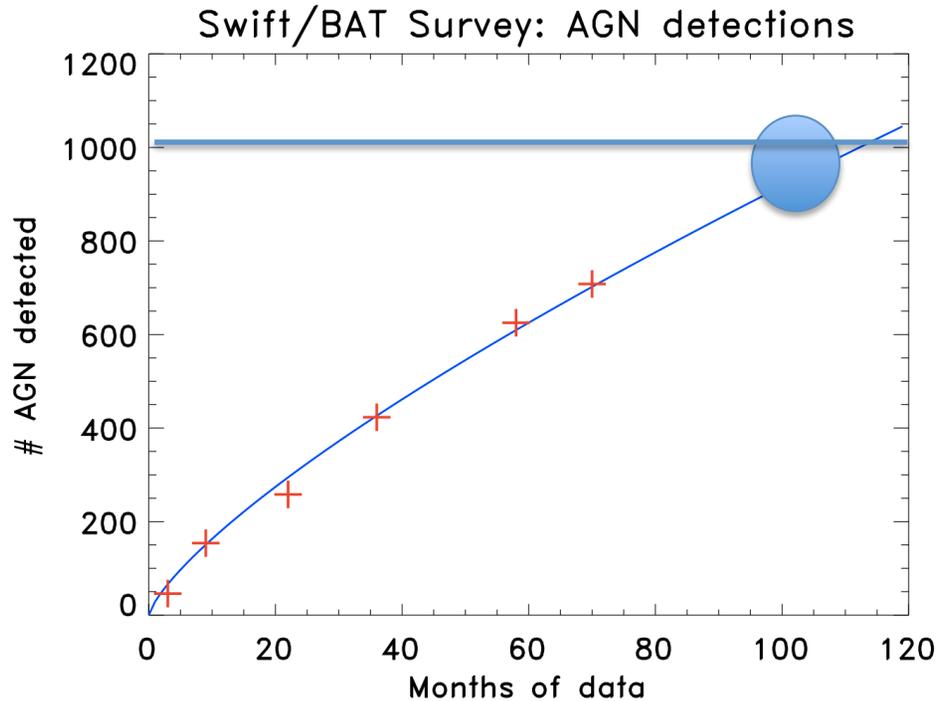
flux

BAT is a Wonderful Instrument

- No evidence of hitting limits after 20Ms of exposure
- Stacking to obtain 7,000Ms works well
- Sensitivity continues to improve as $t^{1/2}$ - within 15% of statistical expectation



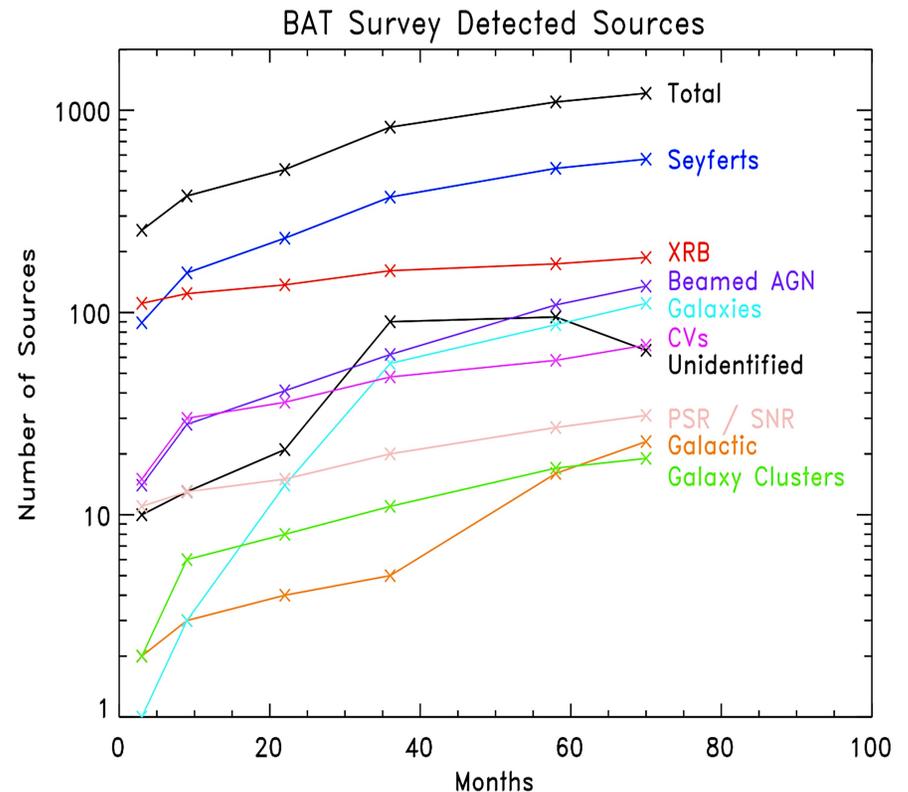
Extended Time Baseline



- Collection of survey data continues -- source numbers increase as $t^{3/4}$ (**1000 AGN in 105 month catalog**)

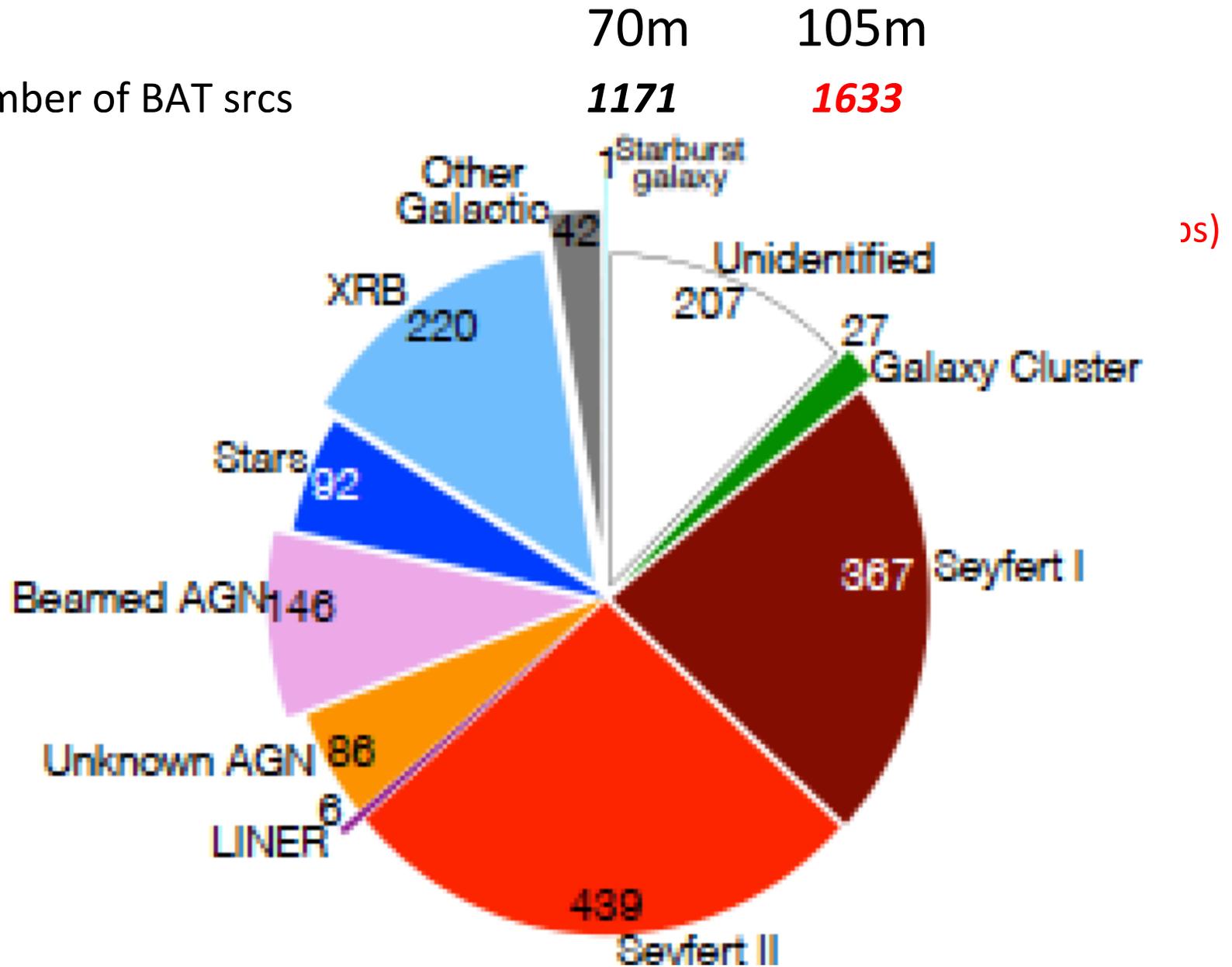
Wide variety of sources
AGN, CVs, X-ray binaries,
clusters of galaxies, SNR,
blazars, pulsars

All sources have spectra and
light curves

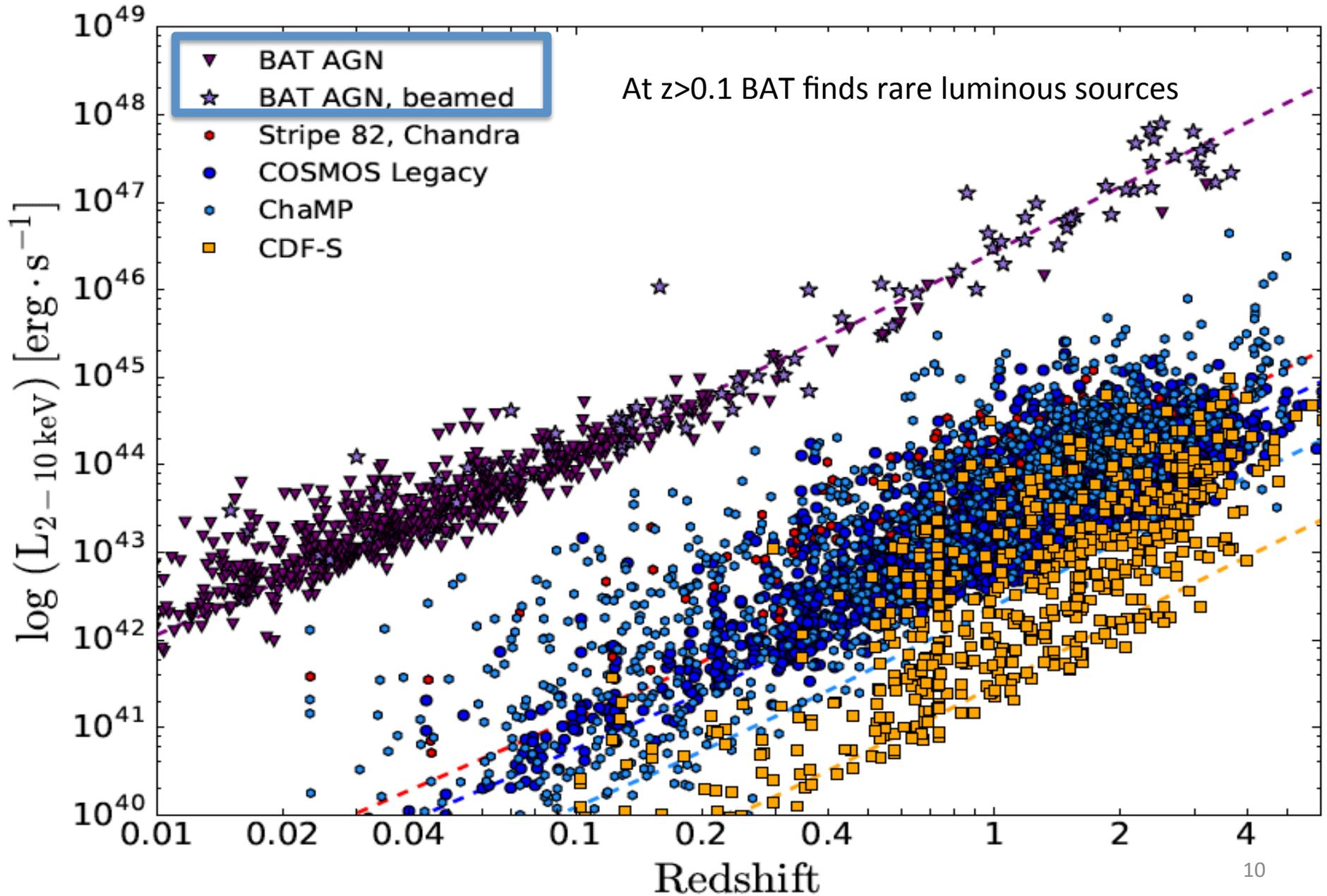


Newest Processing- 105 Months- K. Oh et al ApJ 2018

- Total Number of BAT srcs
- Number of
- Number of



Comparison of BAT to Other Surveys



Focus on the AGN Results

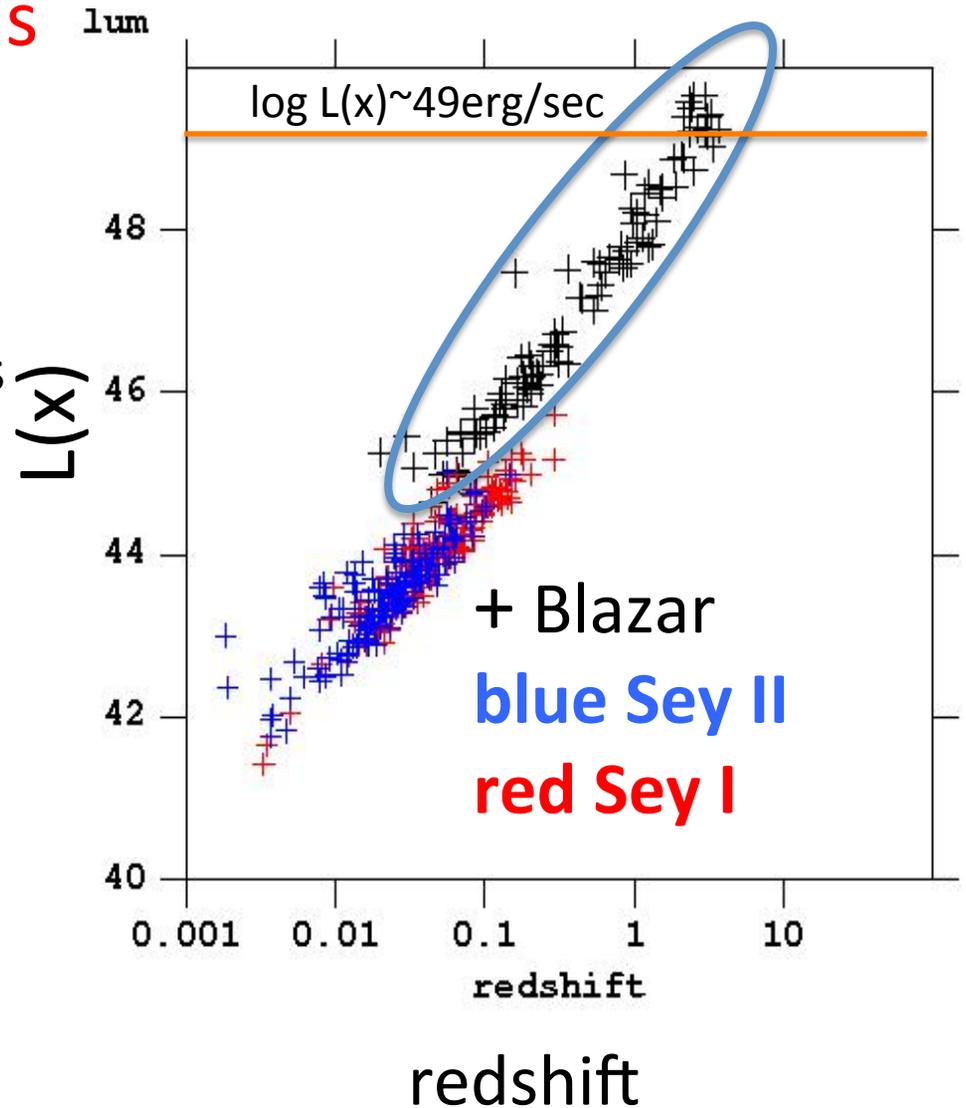
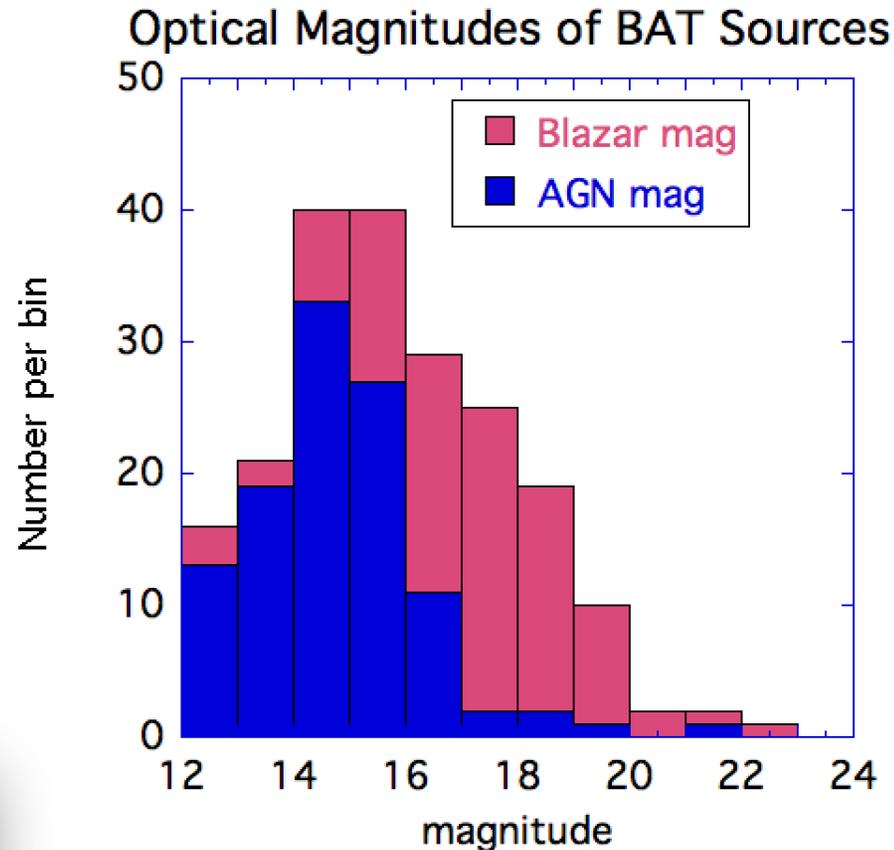
- X-ray, optical, IR and radio follow-up of the BAT survey
 - catalog of >1000 identified AGN selected in the very hard ($E > 14$ keV) band
 - Survey is continuing
 - Anticipate >1400 AGN in next catalog
- Many of these AGN not recognized before (Masetti et al suite of papers)
- The selection of the AGN is based on follow-up observations in the x-ray (esp. Swift XRT, OM) and other wavelength bands which are independent of the host properties (BASS team, Koss et al 2017)
 - a **dedicated Swift XRT program** and XMM and Chandra observations

'Two' Classes of AGN

- Blazars (Bl Lacs and FSRQs) dominate the $z > 0.1$ sample
- 'Normal' AGN dominate the low z sample.

Search for *Very Luminous* High Z Blazars

- optical counterparts are fainter than emission line AGN
- ratio of hard x-ray to 'optical' is very high



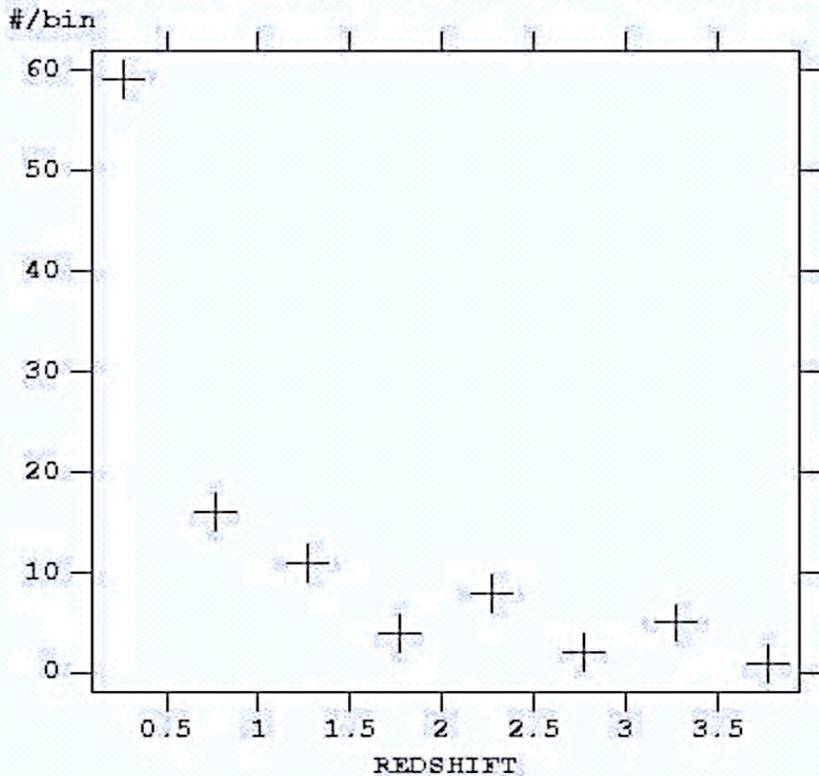
hard to identify without accurate positions- suspect missing quite a few (!)¹³

Search for High Z Blazars

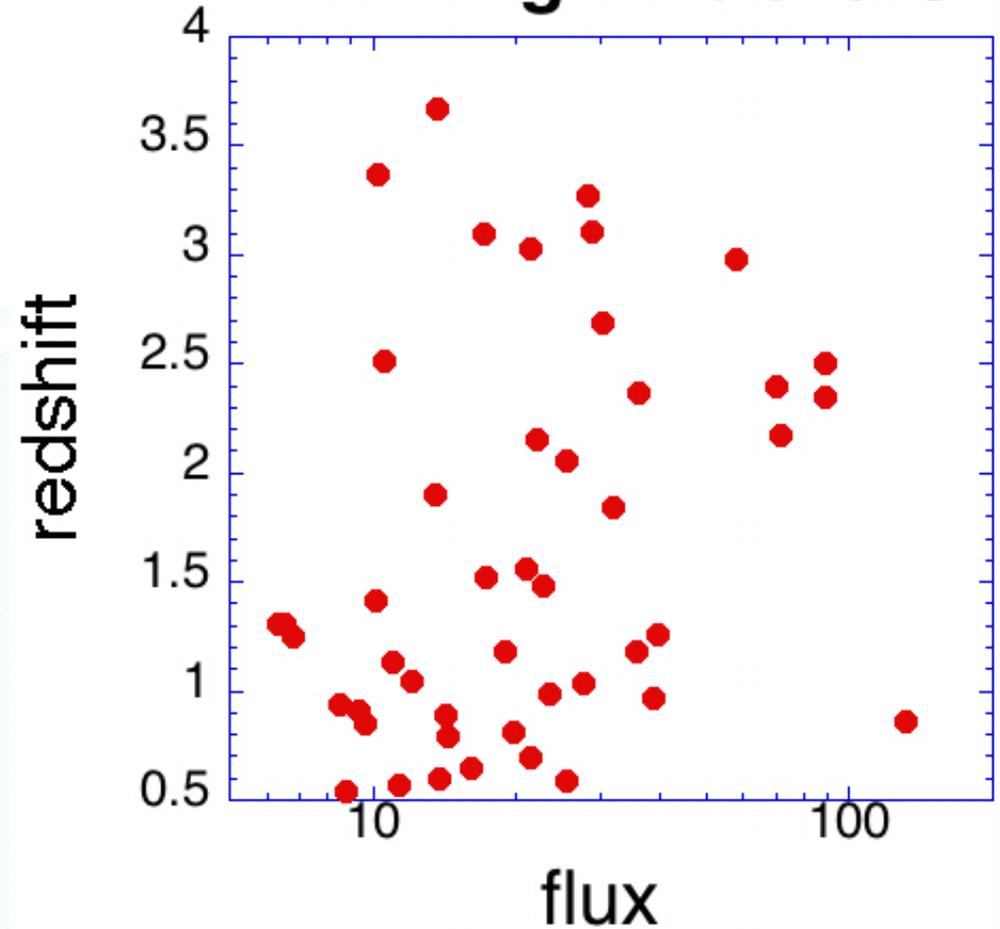
No relation between flux and redshift for hard x-ray selected Blazars

~flat redshift distribution.

Redshift Distribution for BAT Blazars



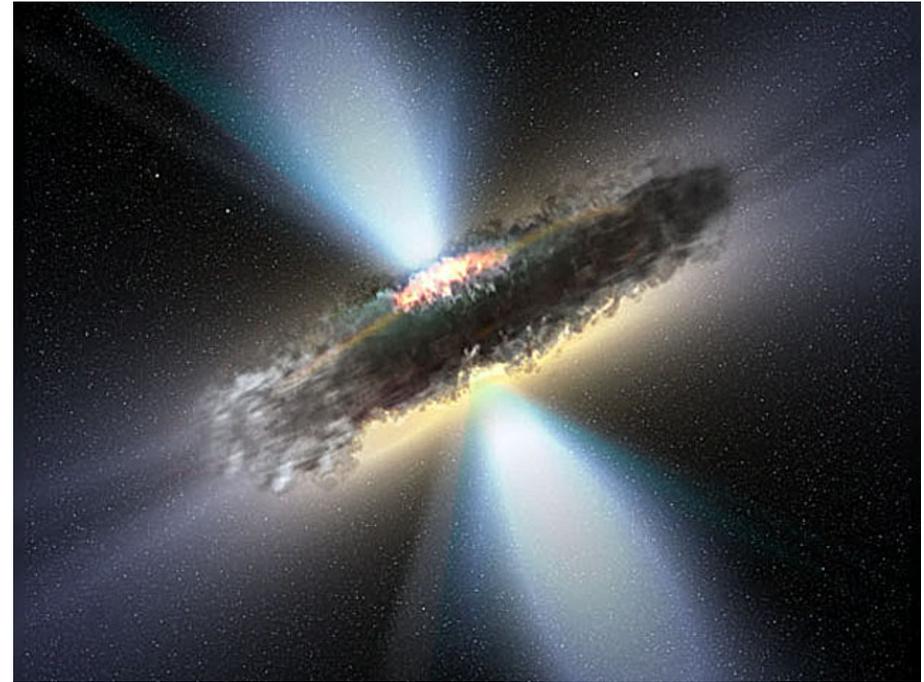
BAT High z blazars



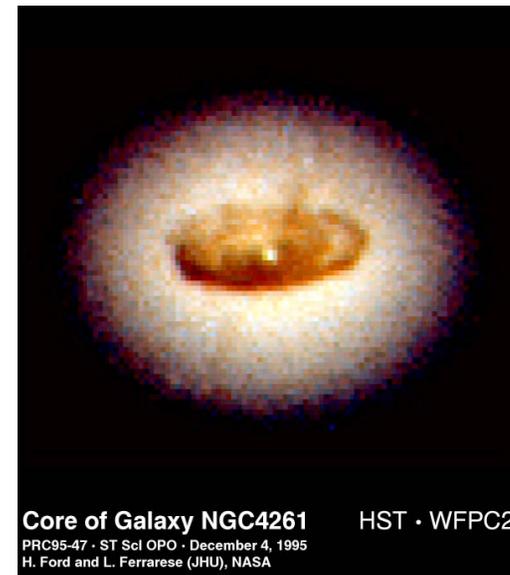
Possibility of very high z objects

"Normal" Active Galaxies (AGN) and X-rays

- The BAT sample: first **'unbiased'** survey of AGN **in local universe**
- no selection effects due to obscuration, galaxy properties or optical or radio properties
 - **Most AGN are 'obscured' in the optical and UV by dust and gas- hard x-rays pass through**
 - **most BAT sources are close ($\langle z \rangle \sim 0.04$) and bright ($M_J \sim 11$): "easy" to study**

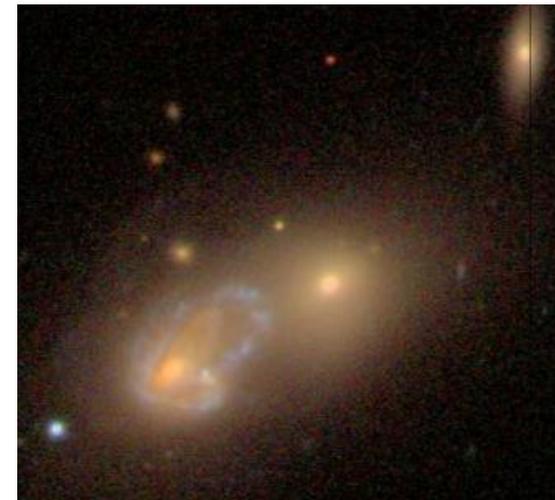
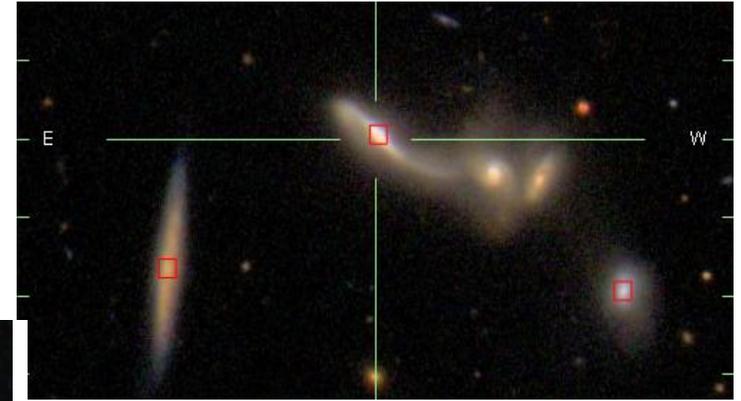
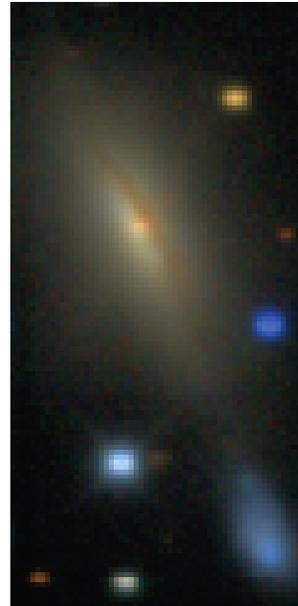


The 'Dark Side' of AGN



BAT Answers the Major Questions

- How many AGN mergers are there really? - **~10x more than we thought**
- Do optical surveys find most of the AGN? **No**
- Have we properly accounted for the energy that AGN release **No**
- Are the properties of 'non-optically' selected AGN different? **yes**
- Does the AGN influence the host or vv?- How would we know? **in progress**



Koss et al 2011

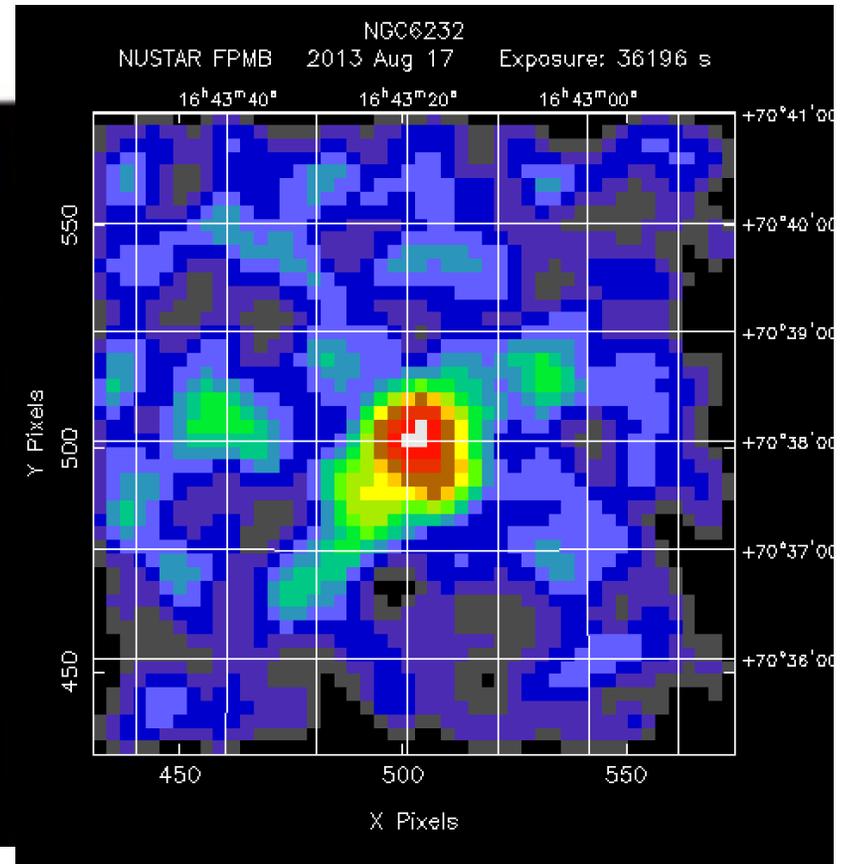
Finding Incredibly Obscured Sources (Koss et al 2018)

NGC 6232, $N(H)=4 \times 10^{24} \text{ cm}^{-2}$, $\tau_{\text{Compton}} \sim 0.7$

15 ks of XRT

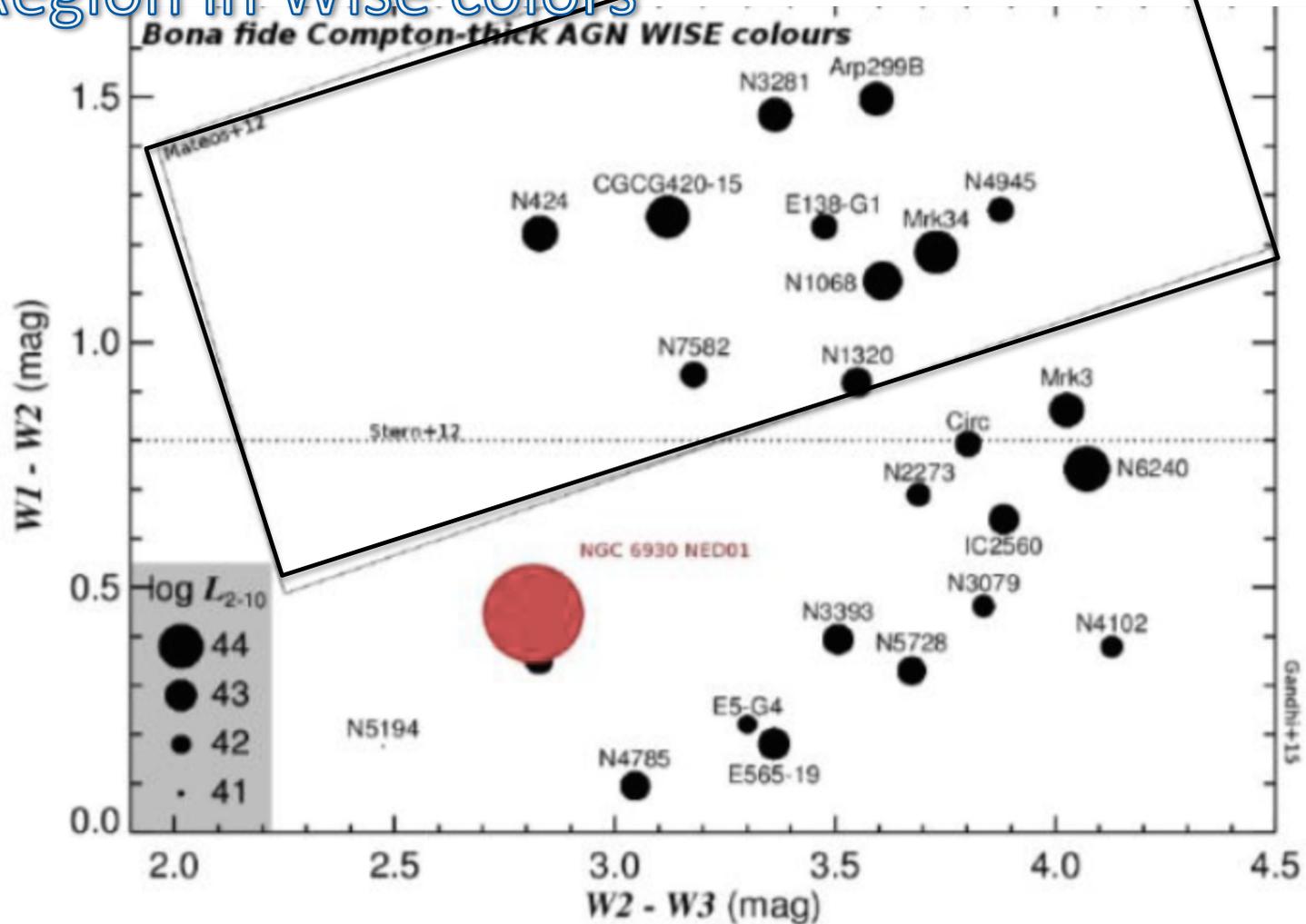


18 ks of NuStar data



IR Colors Miss ~1/2 of the BAT Compton Thick Sources

AGN Region in Wise colors



Different Host Galaxy Properties

- *Major differences* from optical survey properties
 - many more mergers (Koss et al 2010, Parisi et al 2013)
 - host galaxies
 - different optical colors than SDSS sample
 - systematically more massive
 - different distribution of morphologies
 - *Many do not lie on main sequence of star formation*
- These data show- that at low redshift, AGN are *not* drawn from the normal galaxy population

Morphology - Mass

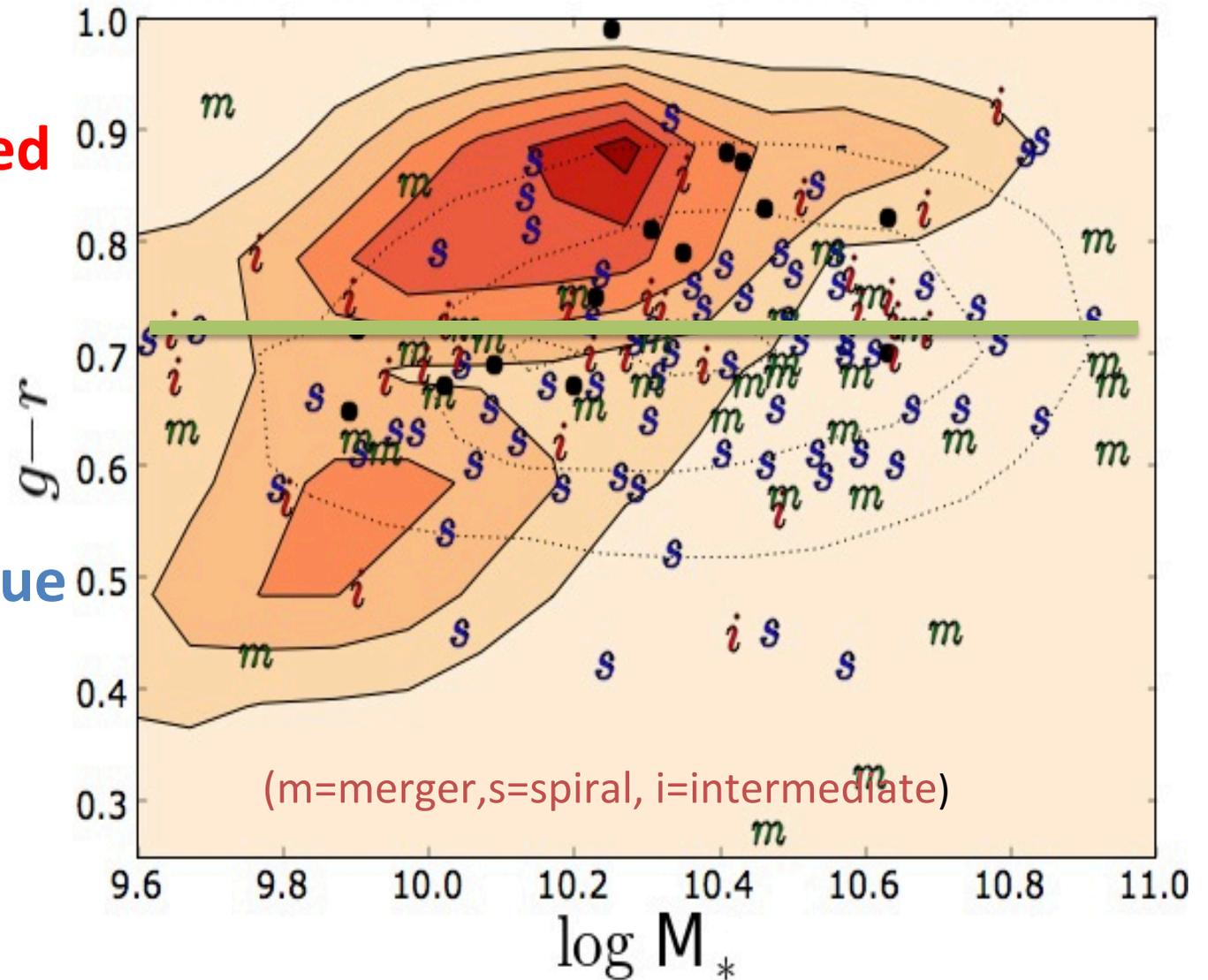
Hosts of BAT
AGN:

more massive,
more mergers,

in 'green
valley' (Koss et al
2011)

Red

Blue



Contours show location of 'normal' galaxies from the SDSS-
ellipticals are red, spirals are blue-
BAT AGN lie in the middle

S=spiral, m=merger, i=indeterminate, =elliptical

What do we gain from continuing the BAT Survey- Going Longer/Deeper ?

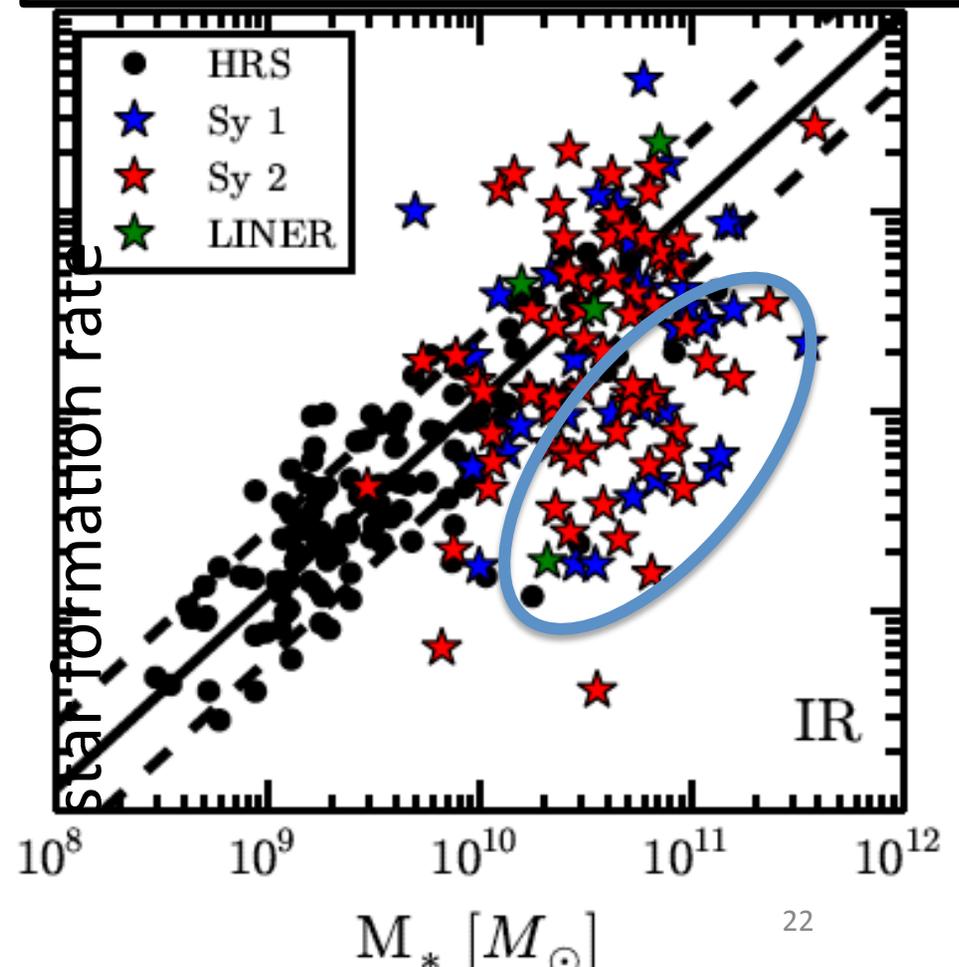
- More sources... obvious
 - More absorbed and Compton thick-**truer picture of AGN population**
 - more unusual sources
 - high z blazars
 - dwarf galaxies
- Better spectra- higher S/N for more objects
 - ability to distinguish models
 - discovery of new phenomena
- Longer light curves- very interesting phenomena

Star Formation in BAT Sample- Smoking Gun of Feedback

~50% of the BAT AGN lie **below** the *main sequence of star formation*, where star forming galaxies lie

- T. Shimizu (2016,2017))
- *Is this the signature of feedback or do AGN preferentially live in galaxies in which star formation is being shut down?*

~50% of AGN hosts display lower levels of star formation than expected



Neil's Legacy

- Neil insisted that the γ -ray burst detector be a hard x-ray detector (*BAT*)
- His focus on science allowed such a long term project (**many new results after 14 years**)
- His support of graduate students was crucial
- The results so far are numerous, important and unexpected and there are many more to come

